Complex System Failure Analysis - Fire Structure Interface

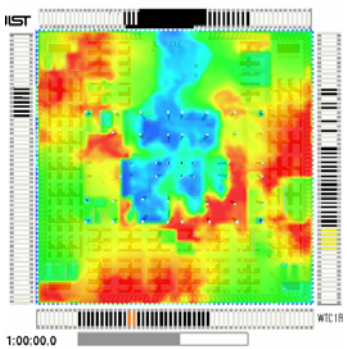
Kuldeep Prasad
Fire Research Division
Building and Fire Research Laboratory

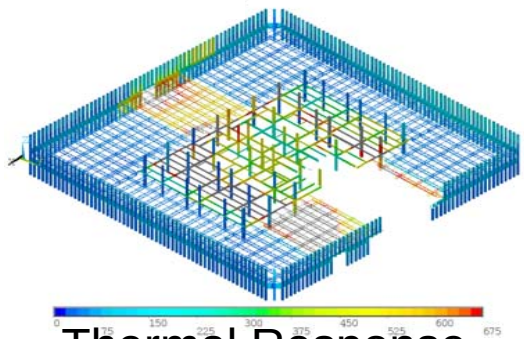
Acknowledgement

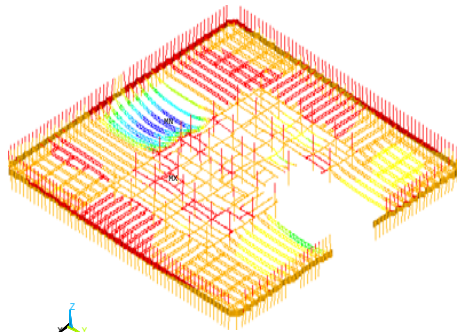
Howard Baum, William Grosshandler (866)
Emil Simiu, Dat Duthinh, Therese McAllister, James St. Pierre (861)
James Filliben, Jeffrey Fong, Geoffrey McFadden, Ron Boisvert (891)
Spencer Quiel (Princeton)

April 3, 2006
Annual Fire Conference

Structural and
Fireproofing Damage







Fire Dynamics

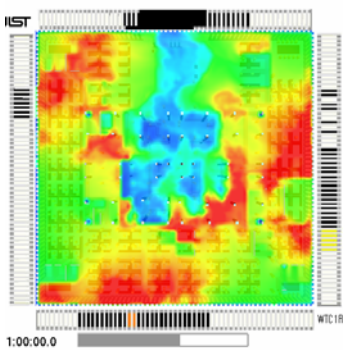
Thermal Response

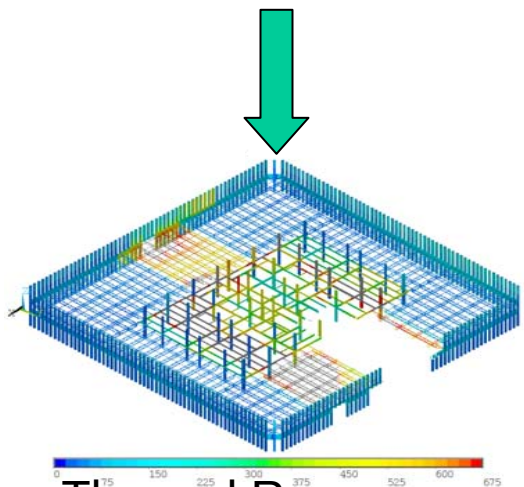
Structural Analysis
Collapse

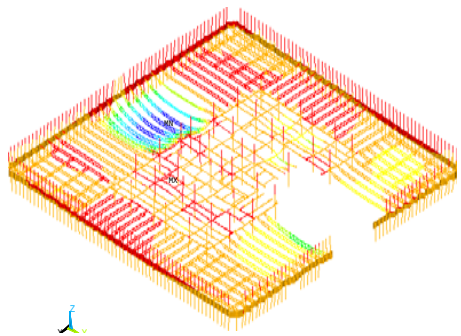
WTC Investigation

Fire Structure Interface

Post WTC Investigation







Fire Dynamics

Thermal Response

Structural Analysis
Collapse

Observations

Fire Dynamics CFD ⟺ Thermal Analysis: FEM ⟺ Stress Analysis, Failure : FEM

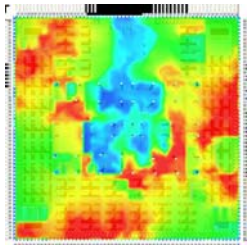
- Solution of the radiative transport equation.
- Couple NIST Fire Dynamics Simulator to Structural Analysis.
  - Spatial and Temporal scales.
  - Numerical Techniques.
  - Complexity of Individual Codes.

} Very Difficult

- Sub-grid scale model : plane layer analysis.
- Fireproofing thickness, variability, damage.

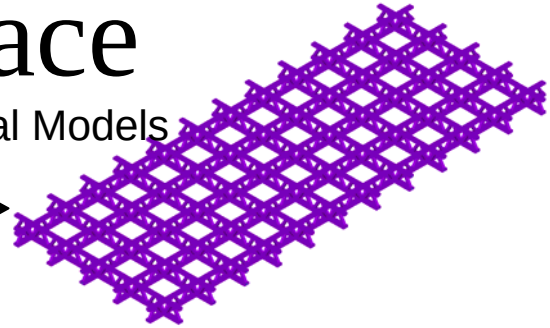
"Coupled Fire Dynamics and Thermal Response of Complex Building Structures", Kuldeep Prasad and Howard Baum, **Proceedings of the Combustion Institute**, 30 (2005) 2255-2262.

Fire Structure Interface



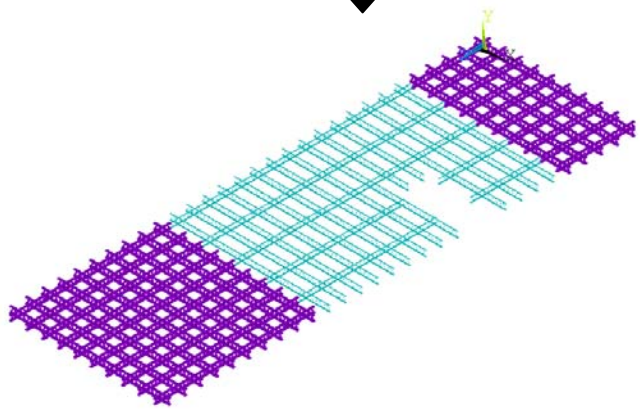
Upper layer temperatures
Layer Height
Absorption coefficients
Lower layer temperature

Thermal Models

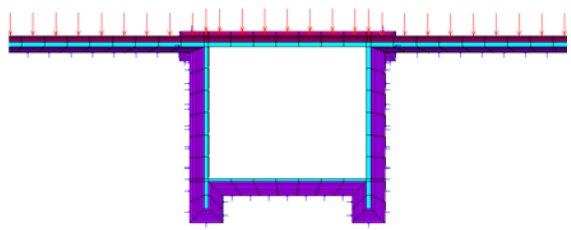


Fireproofing Damage

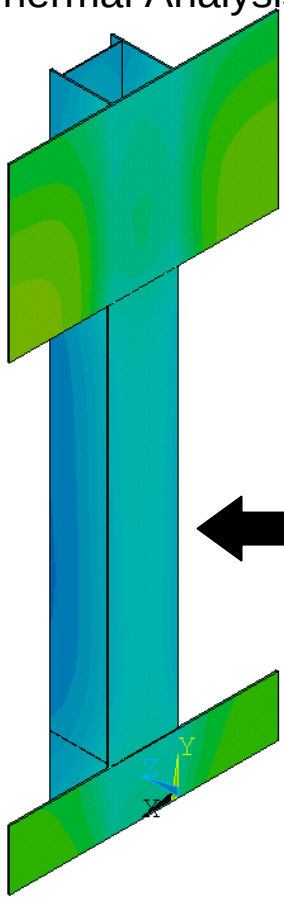
Structural Damage



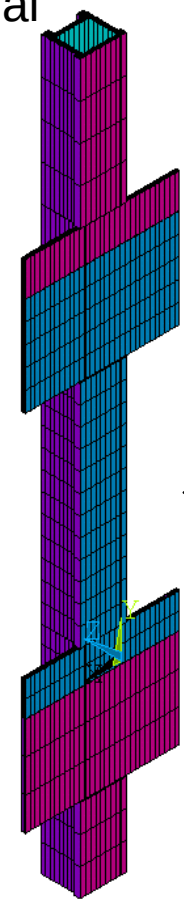
Plane Layer Analysis



3-D Transient Thermal Analysis



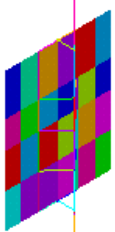
Thermal



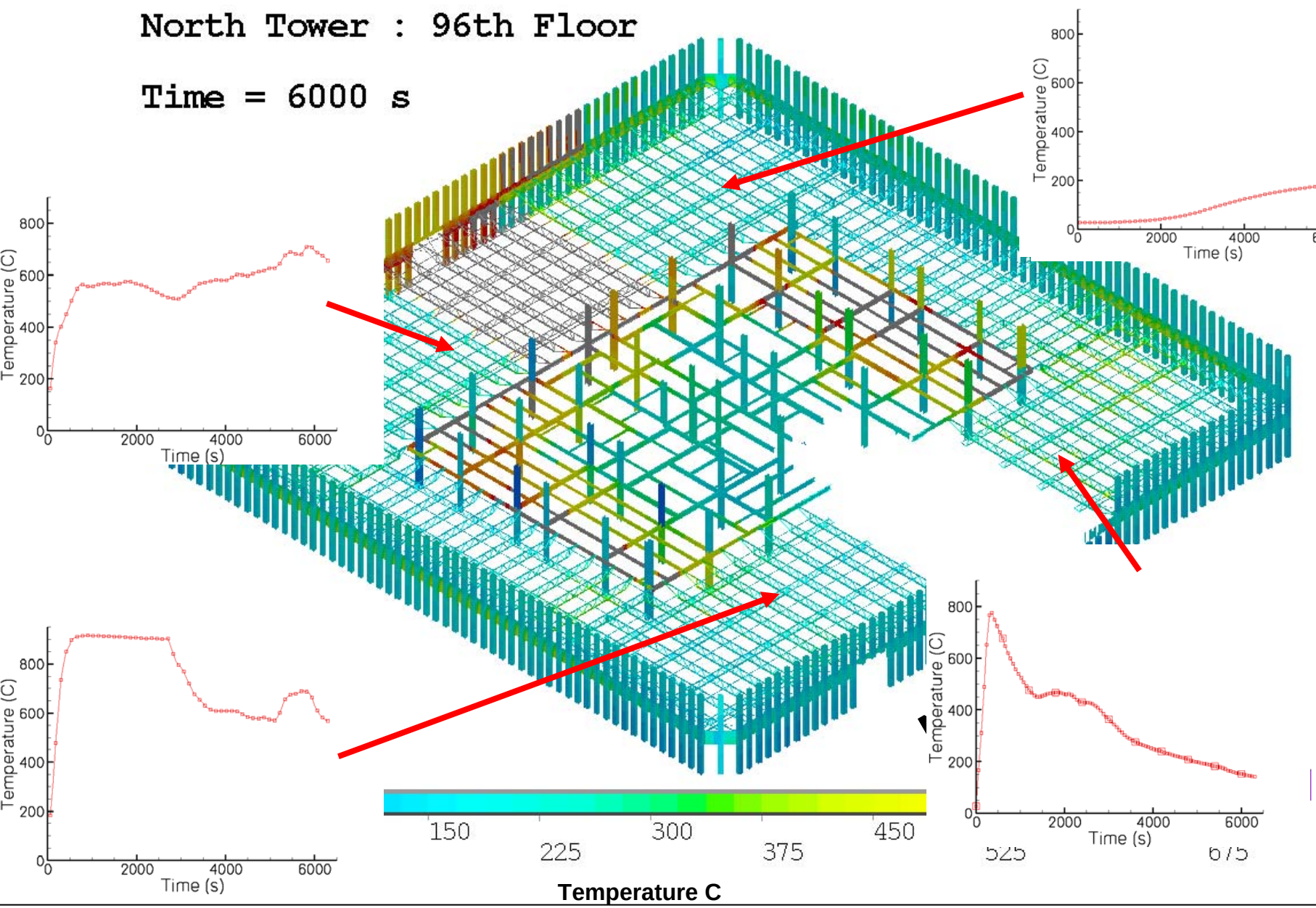
Temperature

Temperature gradient

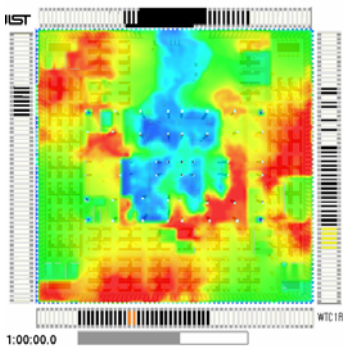
Structural



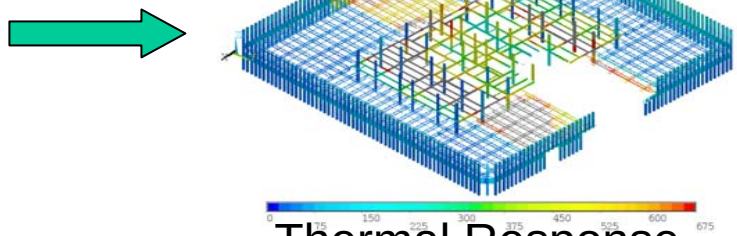
North Tower : Severe Case



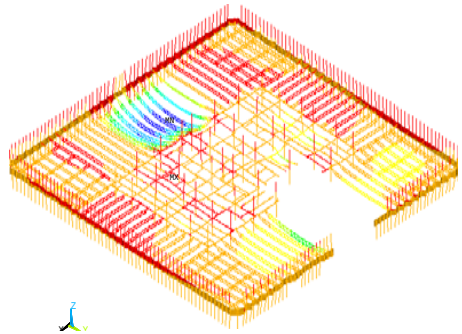
Enhancement to Fire Structure Interface (FSI)



Fire Dynamics



Thermal Response



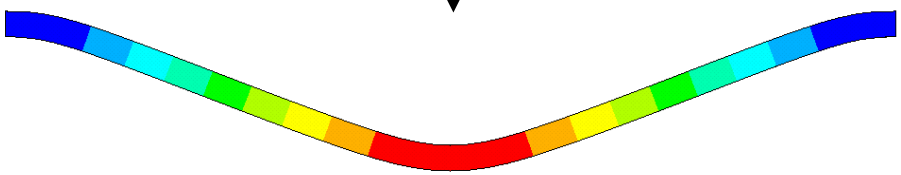
Structural Analysis
Collapse

- As the structural model deforms, the thermal models also evolve simultaneously.
- Change in boundary conditions for thermal model due to large structural deformations.

One way coupling between thermal and structural models

Thermal model

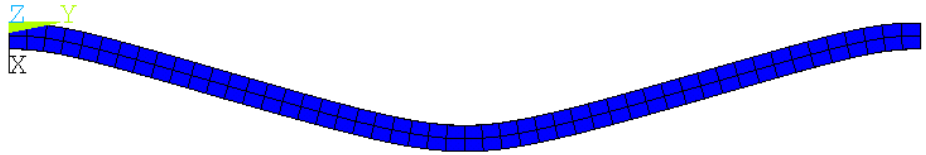
thermal data



Structural model

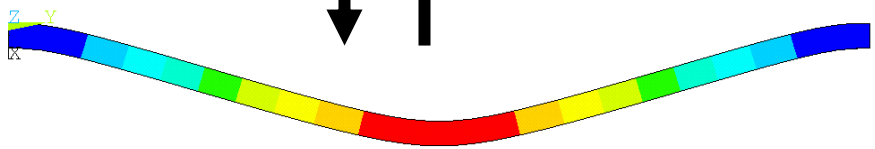
Thermal model does not deform. No change in incident flux.

Two way coupling between thermal and structural models



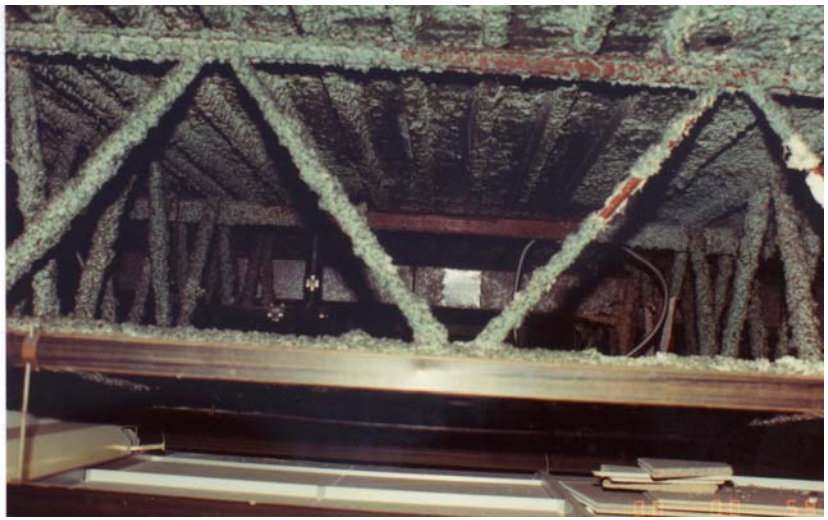
thermal data

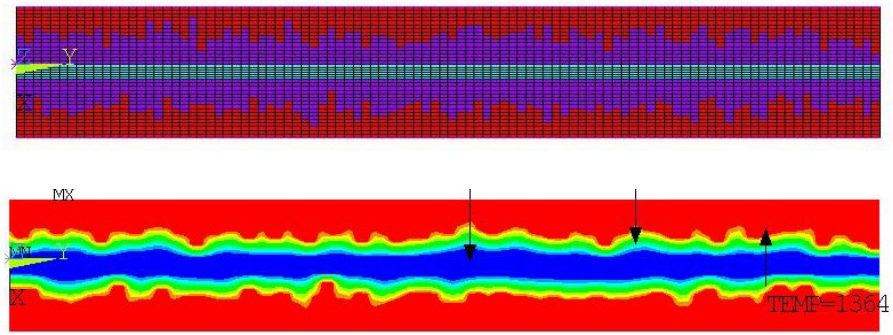
displacement data



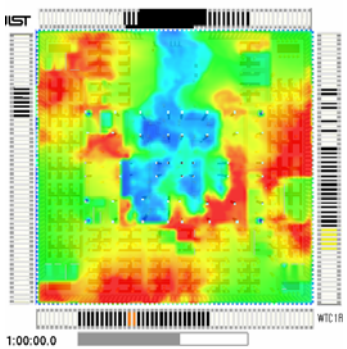
Thermal model tracks structural model. Incident flux changes as structure deforms.

SFRM spalling

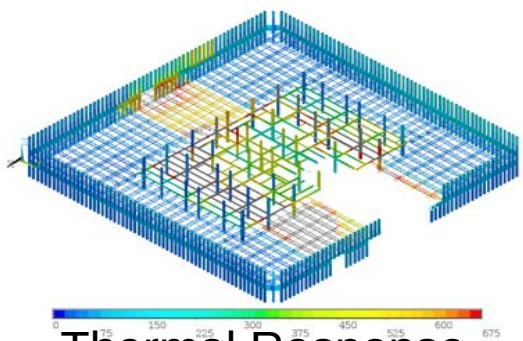




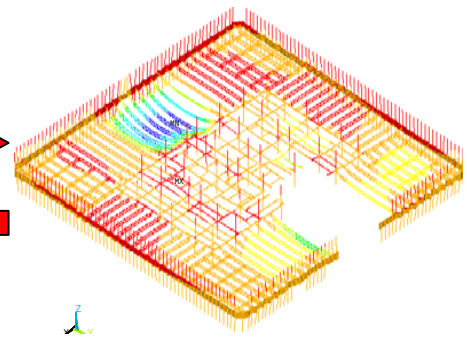
Compatibility of thermal and structural response / models



Fire Dynamics

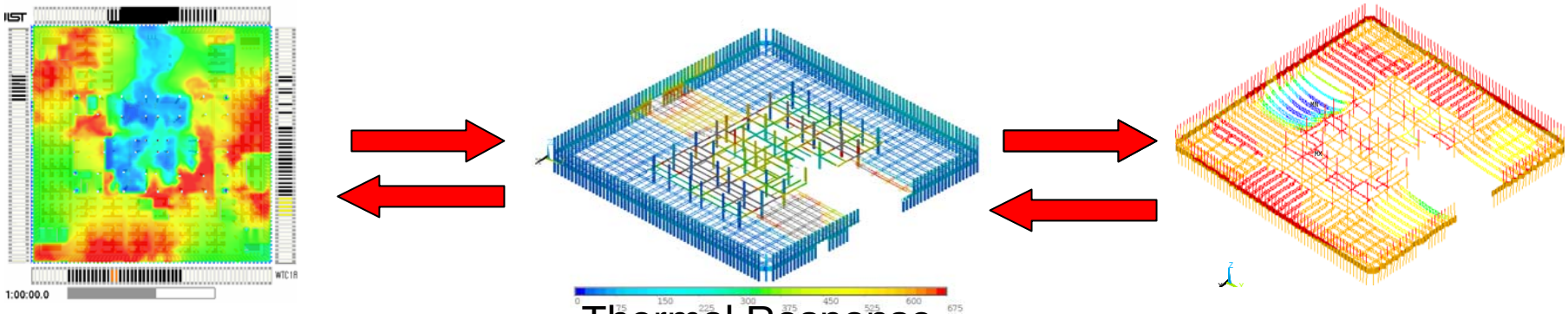


Thermal Response



Structural Analysis
Collapse

Enhancement to Fire Structure Interface (FSI)



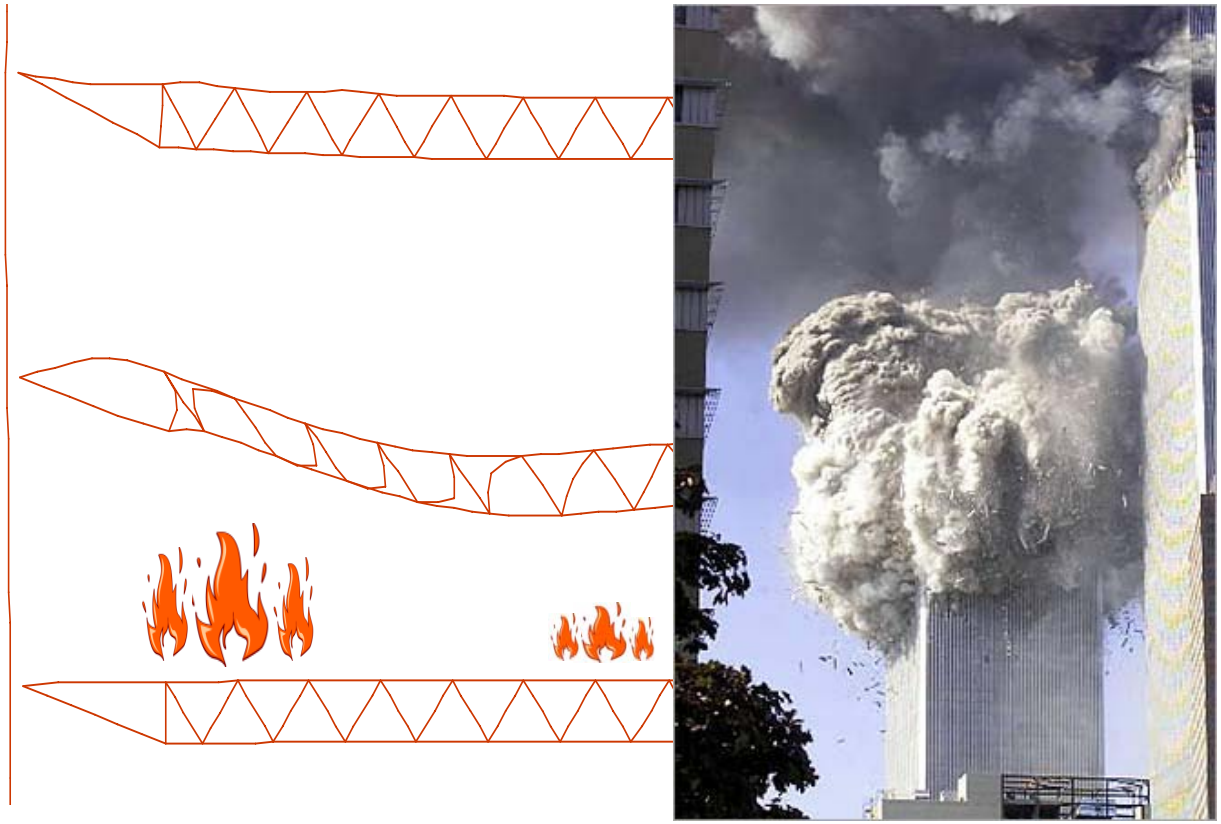
Fire Dynamics

Thermal Response

Structural Analysis
Collapse

- Generalize the FSI software.
- International collaboration : Validation.
- Cardington Test, UL Test.
- SAFIR, LS-DYNA.
- Fully coupled fire – thermal – structural analysis for predicting collapse under extreme loads.

2-D multi-story frame with fire loading



- Need to develop mathematical models and numerical techniques to overcome these difficulties.
- Sensitivity of the analysis to input parameters.
- Simple model for predicting reserve capacity as a function of time.